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Balance energy based on duty cycle method for extending wireless sensor network lifetime

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ABSTRACT

Due to the limited resources acquired by the sensor, energy consumption is one of the main issues that have drawn the attention of researchers in the field of wireless sensor networks (WSN). In this paper, we propose a new protocol based on the duty cycle method and the energy threshold. The suggested protocol aims to balance the traffic among all nodes. As a result, the energy consumption in the entire network will be balanced to prevent service interruptions on a portion of the network. Furthermore, a good result has been obtained compared to other related approaches. As the energy retention was 28%, 33% higher than the compared approach in member nodes, while nearby 33% and 61% in cluster heads. Moreover, the Suggested method outperforms expectations in terms of time, since it reduces the required transfer time by 60% less than the compared approaches. Also, the first dead member node occurs in many later rounds in the suggested method while there is no cluster head node die in 2,000 rounds. Finally, our research objective was met because the energy depletion process in the nodes was nearly convergent.

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1. INTRODUCTION

A wireless sensor network (WSN) is made up of minuscule sensor nodes that are dispersed over a certain region. Applications involving monitoring or surveillance frequently use this network. Each sensor node gathers data from its surroundings and transmits it in a single or multi-hop manner to one or more sink nodes [1], [2]. Each sensor node in such networks is powered by limited energy, where these networks are used in hazardous or difficult to reach, node battery replacement is rarely feasible. The fact that sensor nodes in these networks can run for such a long period on such limited energy is the primary issue [3]. This problem has directed recent research on strategies to extend or in the best case scenario, optimize the network lifespan in WSNs. There is frequently no universal definition for the lifetime of a sensor network because the definition of network lifetime will entirely depend on the network application. The majority of studies introduce a sensor network's lifetime as the period after which its first node is de-energized. Others define the network lifespan as the period during which a predetermined proportion of network nodes are inactive [4].

In other research, a lifespan network is defined as the amount of time for a sensor network's coverage area to be decreased to a specified threshold level for data collection and reporting [5]. The energy is used by many sensor node components. However, each node's communication subsystem consumes the most energy. The activities are carried out in this subsystem: transmitting/receiving data idle listening (IL) for receiving data, and sleeping [6]. The other energy-wasting causes, such as collision and overhearing will be effectively addressed by these activities.

Therefore, the above-mentioned actions are carried out will have a significant impact on each node's lifespan and, consequently, the entire network lifetime. Based on this information, two primary areas of lifespan extension approaches for sensor networks may be identified: methods for energy-efficient routing and methods for duty cycle schedule [7], [8]. To access the greatest energy efficiency, the first area considers the appropriate assignment of various network routes for transmitting and receiving data, and the second one considers an appropriate time mechanism associated with the operations of IL and sleeping. Depending on energy-efficient routing techniques, which are frequently used to solve the maximum lifespan routing problem, several strategies have been proposed for maximizing the lifetime of sensor networks [9].

In the second area of study, approaches for duty cycle scheduling have been used to extend the lifespan of the sensor network. Setting up a sensor node's waking and sleeping is known as a duty cycle schedule. Reducing a sensor node's activity time or, to put it another way, lengthening the time it spends sleeping, or neither receiving nor sending data is the cornerstone of all duty cycle scheduling-based strategies for lifespan extension [10], [11]. Practically, while a sensor node is awaiting data, it should keep its receiver turned on and tune in to the radio station. The term "IL mode" refers to this circumstance. However, a sensor node will waste a lot of energy throughout this process. IL mode's energy consumption is almost approximately to receiving data mode's energy consumption. The two primary kinds of duty cycle scheduling strategies are synchronized and a synchronized methods. It is expected in synchronous approaches that sensor nodes along their communication paths are aware of each other's resting and waking time lengths. Network signalling is heavily taxed when network nodes are synchronized, especially when doing so in huge quantities. In contrast, asynchronous approaches handle node duty cycle scheduling independently of one another, making managing these methods simpler to implement than synchronous ones. They could, however, be ranked worse in terms of longevity and energy efficiency [12].

Srivastava and Mishra [3] developed a mathematical linear programming problem has been developed to represent the maximum lifespan routing problem. The data flow rate on the sensor nodes' connecting links was calculated as a separate set of optimizing parameters in this technique, which is based on centralized modelling. They assumed that the network lifetime was the amount of time until the network's initial node ran out of power. Alshawi *et al.* [4] presented a routing protocol based on one of the swarm algorithms called spider monkey to find the best path from the sensor to the base station through the cluster heads. Singh *et al.* [13] were the first scientists who are given a purely distributed classic answer to this issue. There is no direct connection between the sensor nodes and the sink nodes in any of the approaches provided in [13], [14], hence it has been assumed that all data exchange among the nodes is carried out in a multi-hop manner. However, this supposition will result in an imbalance of energy among the network nodes, and typically, the nodes closest to the sink turn off sooner than the others. As a result, the network lifetime is frequently restricted to that of nodes that are closer to the sink. Arjoune and Kaabouch [15] use both single-hop and multi-hop transmission protocols to describe the lifespan maximization problem based on energy balance to avoid this shortcoming. A distributed protocol called distributed energy balance routing (DEBR) has been developed to implement the system, and this challenge has been described as an integer linear programming problem. Each node in the DEBR protocol is free to select whether to communicate with the sink node directly or through an adjacent node acting as a data relay node. This decision was made under a certain energy cost criterion.

Thomson *et al.* [16] proposed a novel synchronous technique for duty cycle scheduling called adaptive staggered sleep protocol (ASLEEP) to increase the lifespan of a data collecting tree-based WSN. According to certain network factors, such as traffic rate, ASLEEP dynamically modifies the duration of nodes' sleep times. Whereas, in [17]–[19] presented a synchronous medium access control (MAC) protocol S-MAC created particularly for sensor networks, as a way to enhance the performance of the conventional carrier sensing multiple access (CSMA)/collision avoidance (CA) MAC protocol. Periodical listening and sleeping have been employed in S-MAC to schedule each sensor node's duty cycle to decrease the IL time. Dafhalla *et al.* [20] presented and formulated the problem of asynchronous duty cycle scheduling with two key goals in mind: lifespan maximization and total power consumption minimization. Liu *et al.* [21] proposed a routing protocol based on the fuzzy and dstar-lite algorithm to find the best path in a WSN of type heterogeneous.

In this paper, a new protocol is proposed that employs the duty cycle method based on the energy threshold and traffic load to make the nodes get out of the working period and enter the hibernation period. The proposed protocol is divided into several phases, such as a deployment phase, a clustering phase, and a duty cycle phase. The experimental results show that the proposed method has many benefits compared to other related works. The rest paper is organized as follow; section 2 consist of the details of the proposed method, section 3 shows the result, and section 4 explains the conclusion of the proposed method.

2. METHOD

The primary objective of this research is to investigate the mechanisms of existing routing protocols to identify flaws. As a result, a new protocol that addresses these shortcomings is being developed. In this paper, a new protocol is proposed that employs the duty cycle method based on the energy threshold and traffic load to make the nodes get out of the working period and enter the hibernation period. The proposed protocol is divided into several phases, which are described in:

2.1. Deployment phase

In WSN, the sensors are deployed randomly in a specific area in heterogeneous wireless sensor network (HWSN). Some of these sensors have more capabilities than others to increase the probability to choose as cluster heads while the others will be as member nodes. So, in our method, 100 sensors have been spread over 100×100 m, 20 of these sensors are high resources while the other is low resources.

2.2. Clustering phase

The network model is HWSN with a multi-hop between cluster heads and single hop between member nodes to cluster heads. As the clustering is done by using the heed protocol which divides the clusters based on energy and probability. After applying the clustering method, 17 sensors are having been elected as cluster heads and 83 as member nodes. The number of member nodes in each CH is not equal due to the protocol used for clustering depends on the lowest distance to join the cluster. Figure 1 illustrates the network model of the suggested method.

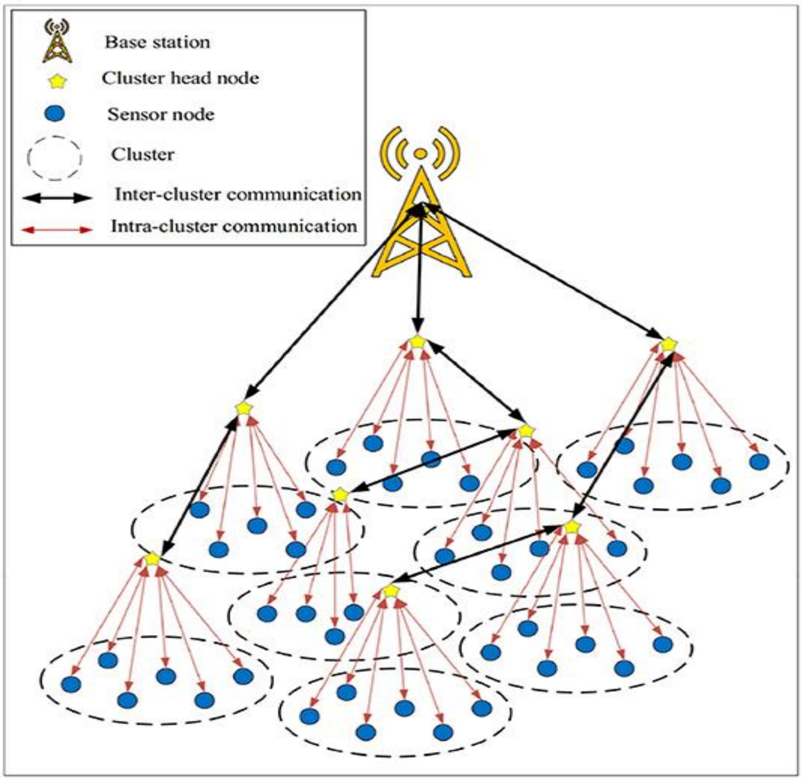

Figure 1. The network model

2.3. Duty cycle phase

A strategy for decreasing energy dissipation in WSN involves regularly putting a node into sleep mode (WSNs). The majority of research specifies a standard duty cycle value for WSNs to accomplish node synchronization [22]–[24]. To reduce energy usage and delay, however, much research suggested adapting the duty cycle to homogeneous traffic circumstances. The lifespan of the nodes based on total energy consumption is calculated in this work, and the impact of the duty cycle on anticipated energy consumption is investigated [25], [26]. For suitable node density, it is demonstrated that the suggested scheme performs noticeably better when compared to a standard scheme. The duty cycle phase in the suggested method is divided into two steps based on the role of the sensor.

2.3.1. Duty cycle in member node

Depending on the energy threshold specified in the proposed algorithm, the nodes enter hibernation mode. As soon as 25% of the sensor's total energy is consumed, the sensor will send a notification (MN sleep=0) to the responsible node (CH) requesting permission to enter the hibernation state. The responsible node (CH) will then make the necessary decision to accept or reject the permission based on the state of the entire cluster, which is determined by several criteria, including: i) is the node that sent the notification a single node within a cluster or not? If it is, the permission will be rejected, ii) is the number of active nodes in the cluster greater than or equal to half of the total number of cluster member nodes? if this is the case, hibernation will be permitted directly, with the hibernation time being recorded, and iii) otherwise, if the number of active nodes in the cluster is less than half of the total number, the current node will be allowed to hibernate, with the hibernation time recorded. After that, the CH must be awakening another node to replace it. As this node is chosen based on hibernation time and the first sleep node will wake up first. As a result, the node will alternate work between them, and this leads to balancing the energy within one cluster to avoid concentrating the load on one node without the other. Figure 2 illustrate all step of the duty cycle in member node.

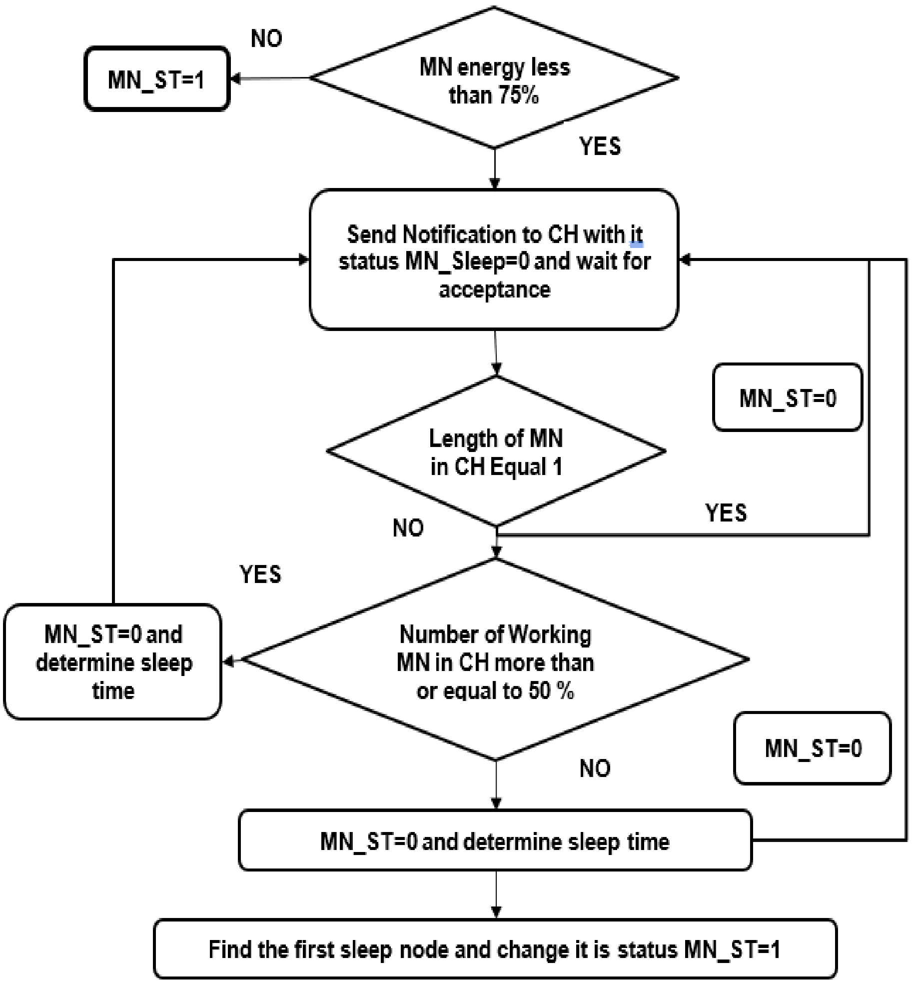

Figure 2. The duty cycle in member node

2.3.2. Duty cycle in cluster head

Depending on the energy threshold specified by the algorithm, cluster nodes also enter a state of hibernation to lessen the traffic load on the cluster head nodes and make energy consumption nearly equal throughout the whole network. It works as follows: as soon as 25% of the cluster head's total energy is consumed, the CH will send a notification (CH_sleep=0) to the base station requesting permission to enter the hibernation state. The base station will take action based on several criteria: i) whether or not the other cluster heads are completely reliant on it. If this is the case, the hibernation request will be rejected to avoid a service interruption, and ii) otherwise if it is not the only path in the other cluster heads, it will be allowed to hibernate with recording a timer for that. Thus, traffic load will be reduced on it.

After that, base station will check the status of each cluster head neighbour, if the number of active neighbours is less than half, base station will wake up the first sleeping node based on hibernate time. So, the number of active nodes for each cluster head must be greater than or equal to half the total number. Then, base station sends an update to the CH to take appropriate action. Figure 3 illustrates the duty cycle in cluster head.

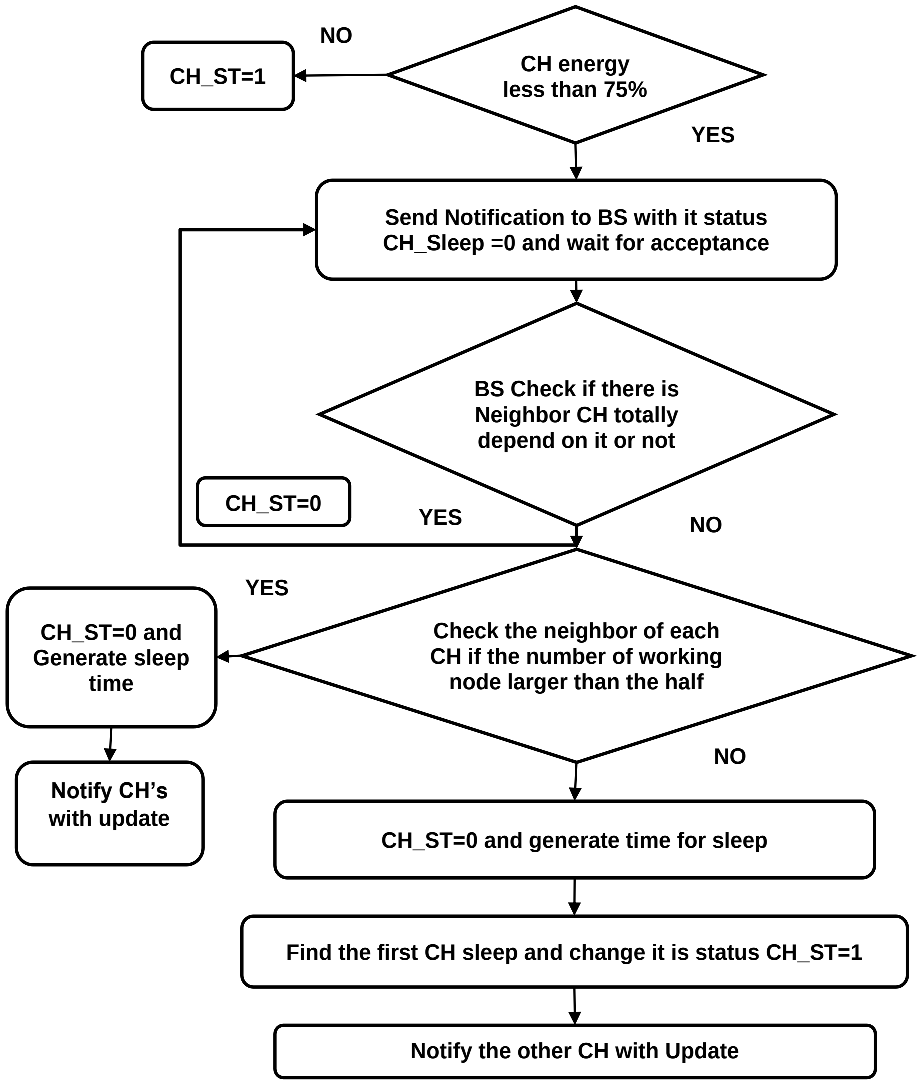

Figure 3. The duty cycle in cluster hesd node

2.3.3. Choose the path for routing

The network's member nodes are responsible for sensing data in the network, while the cluster heads collect it and send it to the base station. When one of the member nodes detects data and transmits it to the CHs, the CHs select the best path to the base station. The best path in the suggested method is detected as follows: if there is a direct connection with the base station, the transmission will be done directly without relying on intermediate nodes. Otherwise, if there is no direct communication with the base station and the transmission will take place from the nearest active cluster head node to the base station until the packet reaches the target as illustrated in Figure 4.

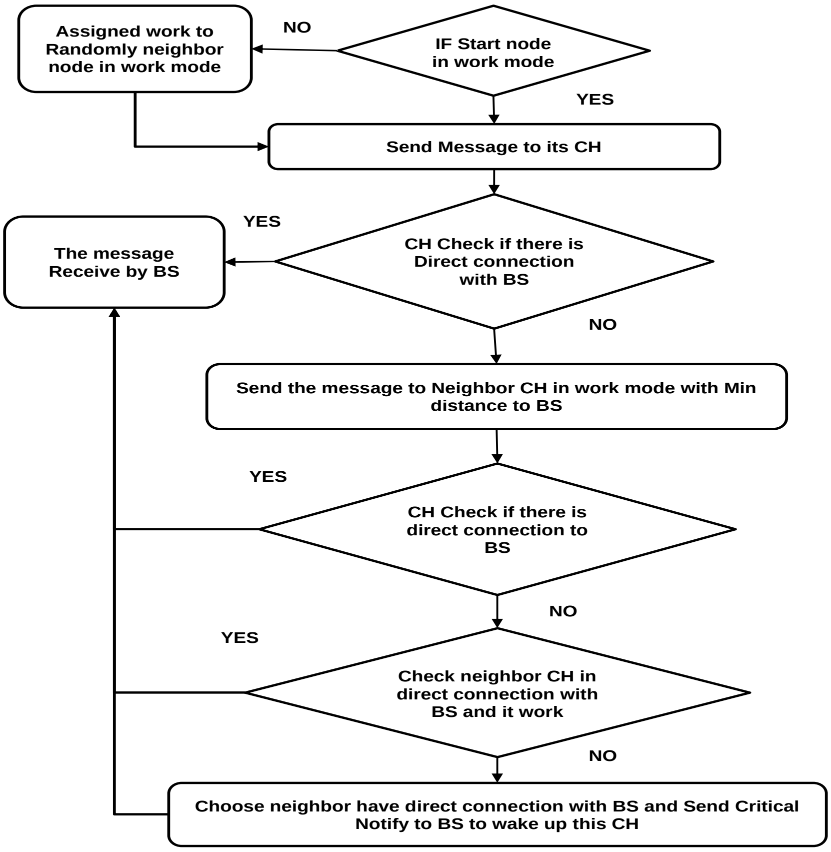

Figure 4. Routing algorithm

3. RESULTS AND DISCUSSION

To evaluate our proposed method, we made a comparison with two other protocols [4], [21] by checking some parameters such as network lifetime since it is the most important point that is focused on by researchers interested in this field. The suggested method compared with others from the side of the average remaining energy in the whole network, the average remaining energy in each node, and the required time to accomplish packet transmission. The simulation is done by using MATLAB with the simulation parameter that is illustrated in Table 1. As illustrated in the result Figures 5-7, the suggested method achieves a better result than fuzzy dstar-lite and spider monkey optimization routing protocol (SMORP) approaches. It keeps the energy at the rate of 28% and 33% in member nodes, and nearby 33% and 61% in cluster heads more than fuzzy dstar-lite and SMORP respectively. Furthermore, the suggested method exceeds expectations in terms of time as well, since it reduced the required time for packet transmission to 60% of the required time in fuzzy dstar-lite and SMORP, respectively.

Table 1. Simulation parameters for all routing methods parameters

Parameters	Value	
Topographical area (meters)	100×100 m	
Sink location (meters)	(50, 50)	
Number of nodes	Low resource	High resource
	80	20
Limit of transmission distance (meters)	High resource sensor=45 m Low resource sensor=25 m	
Initial energy of nodes	High resource sensor=2.5 J Low resource sensor=0.5 J	
No. of transmission packets (rounds)	2,000	
E elec	High resource sensor=100 nJ/bit Low resource sensor=50 nJ/bit	
Eamp	High resource sensor=200 pJ/bit/m^2 Low resource sensor=200 pJ/bit/m^2	
Control data packet length	2 K	

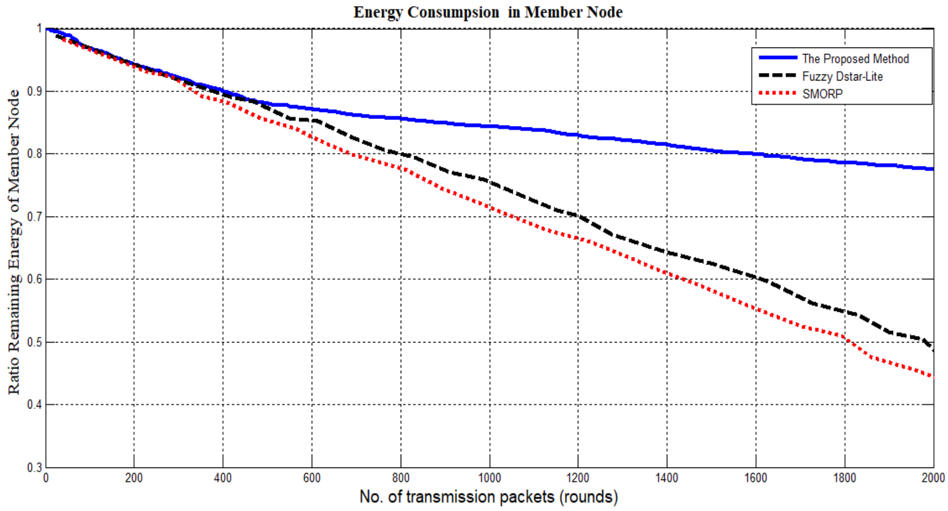

Figure 5. Ratio of remaining energy of member nodes

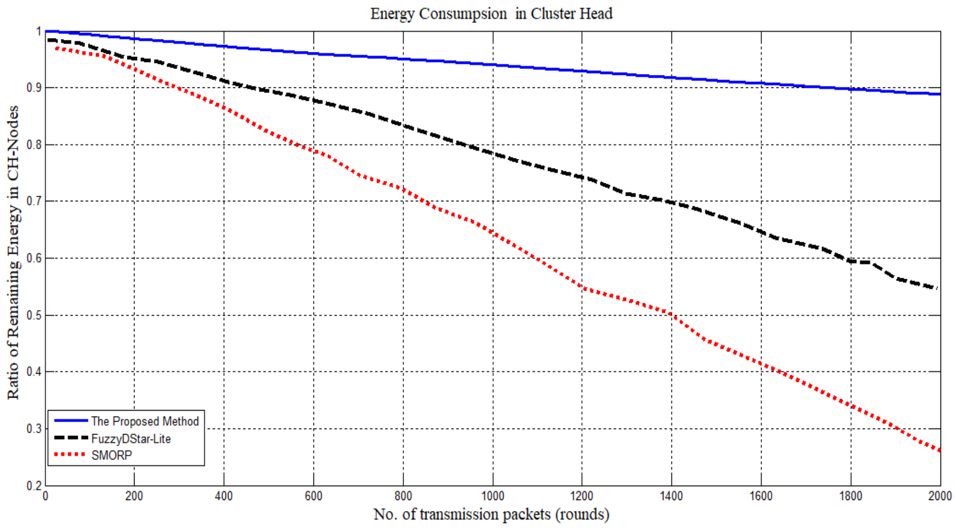

Figure 6. Ratio of remaining energy of cluster head nodes

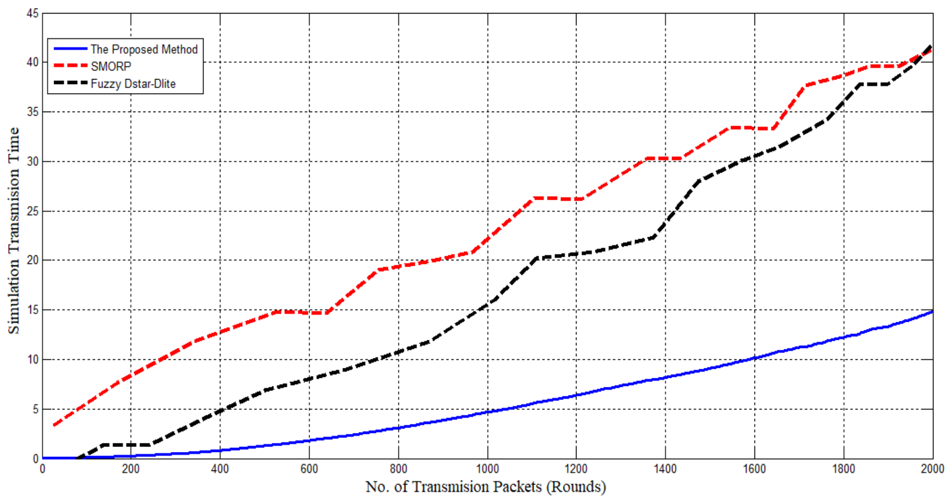

Figure 7. Simulation transmission time

Furthermore, the first dead node in the network after 2,000 rounds is shown in Table 2. As noted, the suggested method stands out for having the first node die too late compared to other methods. Finally, the last two figures are the goal of our proposed method because we sought to balance the energy in the whole network to extend the network's lifetime and prevent service outages in part of the network and that was achieved as illustrated in Figures 8 and 9.

Table 2. The first dead node with 2,000 rounds

Approaches	SMORP	Fuzzy dstar-lite	The proposed method
A lifetime of the first dead N-sensor (rounds)	589	790	1148
A lifetime of the first dead CH-sensor (rounds)	790	1377	-

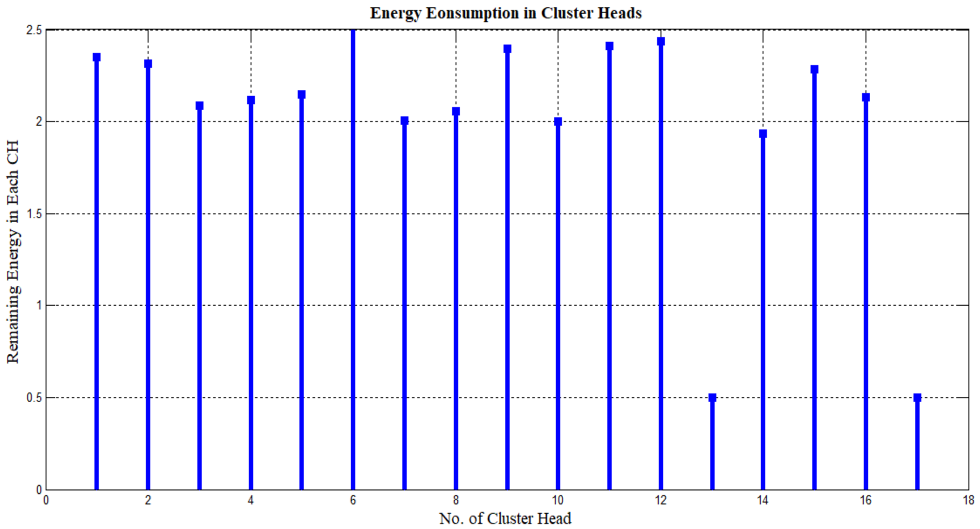

Figure 8. Remaining energy in each cluster after 2000 transmission (rounds)

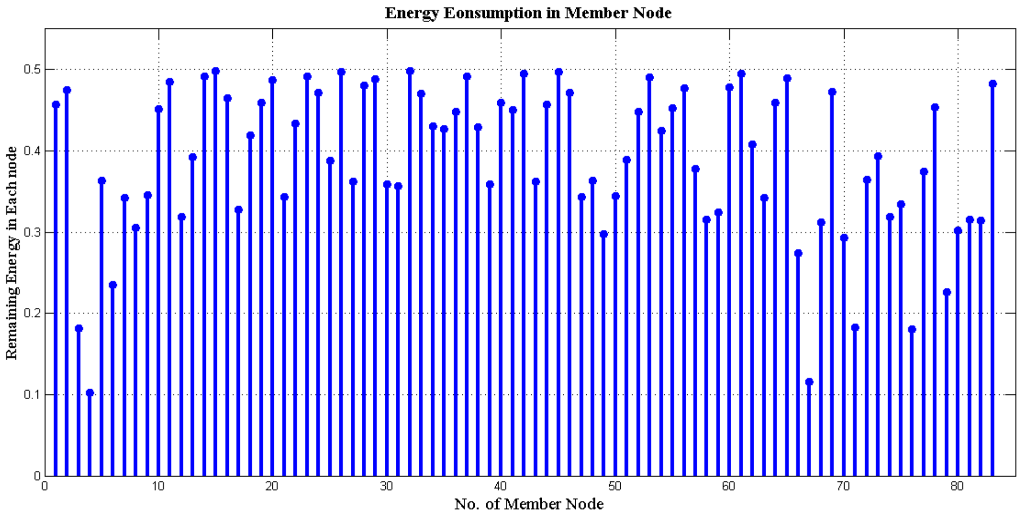

Figure 9. Remaining energy in each member node after 2000 transmission (rounds)

4. CONCLUSION

A large number of studies on WSN in various disciplines have been published. The sensor, which is the main component of the network, has limited resources such as energy, memory, and processing. Thus, energy is the most important factor to consider when conducting research in this field. There are numerous routing papers in WSN, all of which seek to extend the network lifetime, whether the network is homogeneous or heterogeneous.

A new method based on energy threshold using the duty cycle is proposed in this paper. This method seeks not only to extend the network's lifetime but also to make the network work fairly, preventing uneven energy drain and outages of service in some parts of the network. As a result, in the proposed method, energy consumption is balanced across all nodes to reduce the load on some nodes while leaving others. Our research goal was met because the process of energy depletion in the nodes was nearly convergent. As explained in the results, the average remaining energy, required transmission time, and first dead node are all better than the compared methods with it.

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